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Intermodal nodes and external costs: re-thinking the current network organisation

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Abstract

Modern ports are part of intermodal and international networks and have great effects at regional level, influencing both the efficiency of the local markets and the external costs of the served industries. Several studies point out that modern ports need to be included in an efficient network system in order to exploit all their potential. Further, concerning the role of the ports within the whole supply chain, key elements are the location and organization of intermediate facilities – such as logistic parks or inland ports – that heavily affect the effectiveness of the logistic corridors. The accuracy in designing a logistic system can have a big impact on the externalities induced by the transportation, too. New and adequate infrastructures can reduce transport congestions, pollution and accidents.

The proposed study evaluates potential locations of inland ports that might serve a market through different alternatives, in terms of transport modes, costs and distances. The present study has the additional goal of including the external costs in the decision process. For this scope, a linear programming model with both continuous and binary decision variables is given. The required parameters and the constraints of the problem are shown, together with real data concerning the Italian north-western regions and the related infrastructures. Thanks to the proposed model, different intermodal freight logistic networks are compared; in particular, a sensitivity analysis on both the rail capacity and external costs is performed. Note that the outcomes can be used for improving current transport policies that might foster a more efficient and less impacting hinterland transport solution.

Keywords: Intermodal Transport; Cost Internalization; External Cost; Logistic network.

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1. Introduction

International transports are based on complex networks of services that involve a plurality of actors and transport solutions in order to make possible efficient globalised origin – destination connections (e.g. Meersman et al, 2009). For these reasons, all possible routes between a port and its own hinterland represent strategic links able to foster the port efficiency and its competitiveness (e.g. Tongzon, 2009). Several evidences show that well connected hinterlands might increase port competitiveness (e.g. Ferrari et al., 2011) and efficient uses of intermodal transport – in terms of either logistic parks or inland ports – might enlarge port catchment areas (e.g. Notteboom and Rodrigue, 2008).

Note that the connections between a port and its hinterland are not just important for efficiency reasons, but also for the overall costs arising from different transport solutions; such costs account not only direct private cost components but also external ones (e.g. Arnold et al., 2004; Iannone, 2012). Starting from Pigou (1932), external costs of any economic activity gain importance due to the divergence between the perceived “private” costs of a specific economic behaviour and the real overall costs, quite frequently including external costs, such as the environmental ones. In the maritime academic literature this issue has been seldomly studied until the ‘90s, when it became one of the major concerns (e.g. Lakshmanan et al. 2001; Meersman et al., 1998); in particular, many studies tried to evaluate the discrepancy between the private perceived costs of a given transport solution and its actual cost for the society. Cost estimations varied over the time due to the difficulties in clearly evaluating both the external effects and their range of impact (e.g. Maibach et al., 2008). Despite this, external costs have recently been deeply studied, also under many EU projects, aiming, for instance, at assuring their internalization (e.g. eurovignette); however, only few studies try to associate external costs to the optimization of intermodal transport solutions (e.g. Janic, 2007; Arnold et al., 2004).

In the recent literature, many studies focus on the effective flow distribution in a determined hinterland (e.g. Racunica and Wynter 2005; Notteboom and Rodrigue, 2008; Ambrosino and Sciomachen, 2012), the problem of internalizing the transport costs (e.g. Grosso, 2011) or determining the market areas of intermodal (rail-road) container terminals (Limbourg and Jourquin, 2010); relevance is given to the impact of recent EU transport policies on both the cost internalization and its effects on the transport patterns (e.g. Ferrari and Tei, 2012; Limbourg and Jourquin, 2009). Recent studies have analysed the most effective flow distribution in a given port hinterland (e.g. Iannone, 2012), taking into account not only the transportation costs but also the external ones (Santos et al., 2015) studying the problem through a case study approach. As recently remarked (Troch et al.

2015), actions should be taken to make rail freight and intermodality a valuable option. The present paper aims to contribute in this sense: a mixed integer linear programming (MILP) model has been developed for designing a distribution network with the aim of: i) locating inland ports within a specific hinterland; ii) defining the optimal distribution flow. Two competing transport modes are considered, namely rail and road; such transport modes can be combined generating the additional intermodal transport modality. The location and flow distribution decisions are taken with the aim of minimizing the overall distribution costs, expressed by the transportation and externality costs and those associated with the inland ports. A real case scenario, referring to the North Western Italian regions, is deeply analysed; the data used have been provided by the Italian National Customs for the Ligurian ports (Genoa, La Spezia and Savona) and refer to 2011 (the last full available year). Moreover, infrastructural data have been collected for being able to draw the network analysed by the proposed model; more precisely, the whole highway and railway networks of the Italian regions under study have been considered. Further, three candidate inland ports have been analysed to choose the best one/ones for defining the distribution network, as it will be described in the following sections. Finally, in this study we refer to an inland port as a facility characterised by “a rail (or a barge) terminal that is linked to a maritime terminal with regular inland transport services” having an intermodal terminal within its boundaries, as defined by Rodrigue et al. (2013).

The paper is structured as follows. After this introduction, Section 2 focuses on the regional and port characteristics of the considered area, while Section 3 is dedicated to the model description. Section 4 presents the results applied to the proposed case study and discusses them also performing a sensitivity analysis on the optimal solution. Finally, Section 5 addresses conclusions and provides insights for future research developments.

2. Regional framework

In Italy the freight distribution is mainly based on an extensive use of the road transport; this mode is also dominant in the volume of cargo generated by the domestic seaports (e.g. Consulta Nazionale per l'Autotrasporto e la Logistica, 2011). The statistics produced by the European Environmental Agency (EEA, 2015; EEA, 2010), as well as several relevant literature (e.g. Iannone, 2012) and the last National Logistics Plan (Consulta Nazionale per l'Autotrasporto e la Logistica, 2011), highlight how such an unbalanced modal split deeply impacts on the environment, due to the dominant role of the road transport. To give an idea, according to Pastori (2015), only less than 10% of the cargo handled by the port of Genoa is shipped by rail. This issue has been deeply analyzed; consequently,

several national projects are now trying to deal with the externalities generated by trucks (e.g. De Martino et al., 2013). While modal shift policies are often based on incentives to make modal alternatives more convenient – as for the Ecobonus that in Italy characterises the Motorways of the Sea (e.g. Tei and Ferrari, 2012) – less attention has been paid on policies able to internalize the external costs. This issue is mainly due to both the poor political consensus given by these latter policies and the difficulty of applying them. Nevertheless, the definition of more efficient transport solutions – considering the overall induced costs – is essential in order to minimize the above mentioned costs.

Concerning the cost internalization, Maibach et al. (2008) make evidence that the road transport results much more expensive when the external costs are considered along with the private ones. Among the main external costs, the “Handbook on estimation of external costs in the transport sector” (Maibach et al., 2008) takes into consideration three main components: pollution (atmospheric and noise related one), risk (e.g. increasing probability to have an accident) and congestion. Other specific external costs have been also considered in the handbook; however, not all of them can be easily adapted to all European contexts or transport solutions, as for the climate change effects.

It is important to underline that external costs not only relate to “environmental” aspects but also to some side effects that can have a great impact also on the network efficiency; among these, the main one is the congestion, that can heavily affect the efficiency of the transportation system. For this reason, many authors (e.g. Janic, 2007) show that external costs internalization might positively impact on the rationalization of the flows, also incentivising the use of intermodality due to a better mix among the transport solutions.

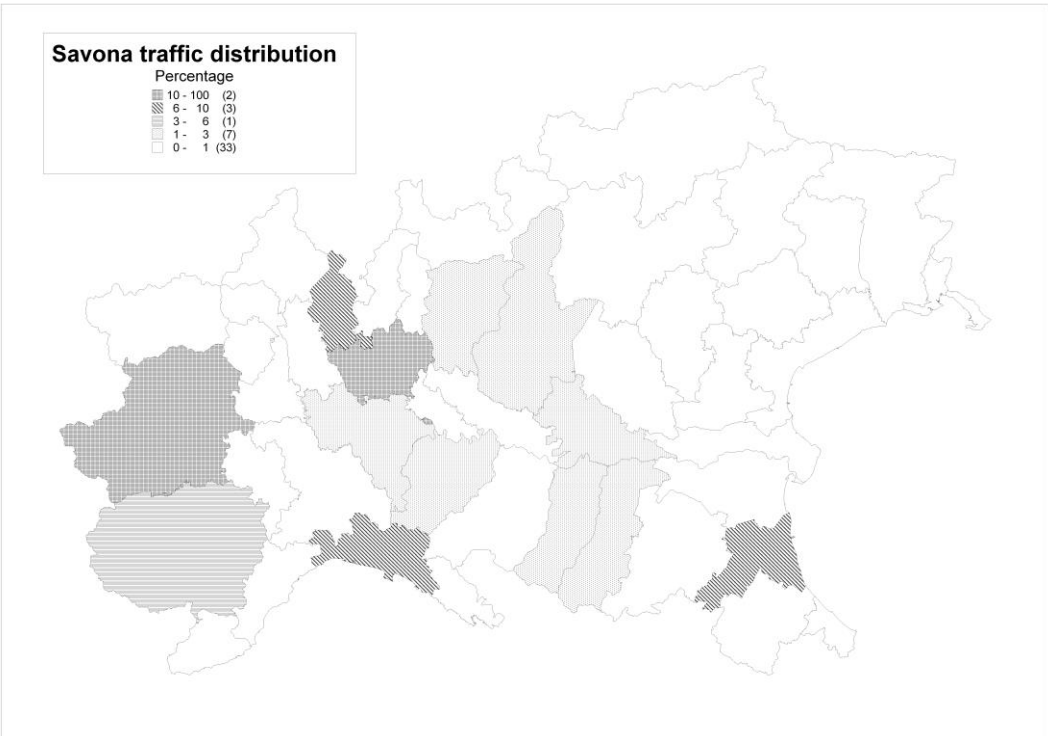
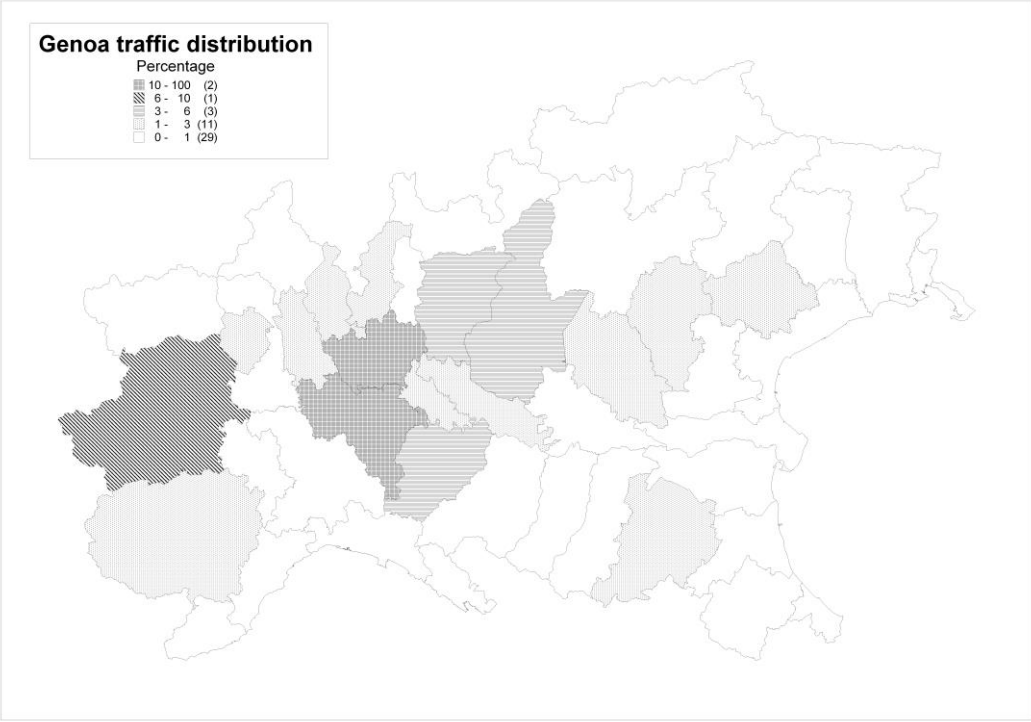
2.1 The collected data

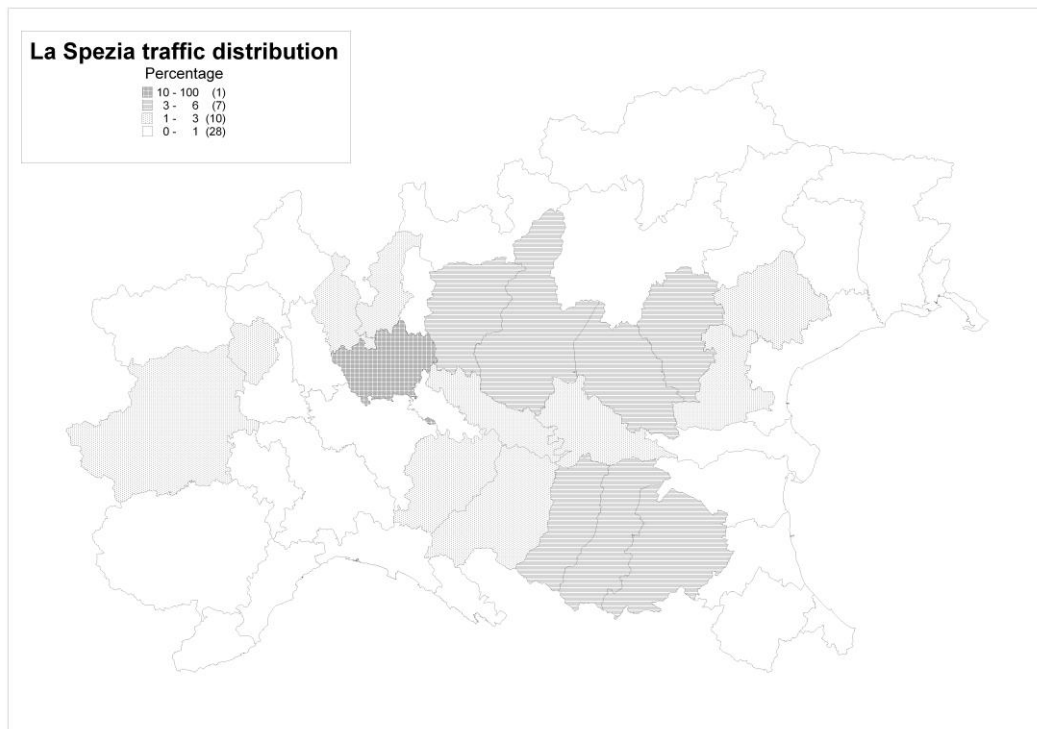
This study starts with the analysis of the freight distribution of three of the major Italian ports, that is Genoa, La Spezia and Savona. In fact, in 2014 Ligurian ports accounted for about 35% of the Italian container traffic – being the greatest gateway port region in Italy – and for more than 18% of the overall Italian port throughput (Assoporti, 2015). Port hinterlands are quite similar, even if some regions concentrate a great share of the three ports’ activity, as shown in Figure 1, where NUTS-3 regions are used as basic geographical unit to map the distribution flow. In particular, Figure 1 shows the import distribution of the containerised cargo, as it is used in the proposed analysis.

In the present study we focus on the import flow of containerised cargo. In fact, presently in Italy the containerised cargo is the only one able to be competitive using both the rail and the road transport

solutions (with different level of performance); further, ports, as well as inland ports, are used to aggregate all the flow coming from the same point and going to close destinations.

Figure 1: Containerised import distribution (port-NUTS3 flows)





Source: Own elaboration form Customs Database, 2012.

Considering the 2011 spatial distribution of the import containerised cargoes handled by the three Ligurian ports (see Figure 1), it is important to underline a substantial overlapping in the catchment areas between the ports of Savona and Genoa – basically corresponding to Piedmont (in particular Turin and Cuneo) and Lombardy (in particular Milan) regions; La Spezia seems to be more focused on cargoes directed to the Emilia-Romagna region. Despite the geographical concentration of part of the traffic, another peculiarity of the considered ports is the wide range of the catchment area. For instance, the smallest studied container port (i.e. Savona) attracts cargos from the Venice region, despite the presence of closer ports specialised in container activity, such as Venice and Trieste.

Moreover, all the studied ports have several plans to expand their container activities thanks to new terminals; therefore, it is crucial to study the possibility of using the rail network for the cargo distribution.

As said, the strict majority of the freight is currently delivered by road (according to Pastori (2015) and the related port authorities' statistics, road solutions account for more than 90% in Genoa and Savona and more than 80% in La Spezia) while only two inland ports are presently active; one inland port is located in the Alessandria Province and receives flows from the port of Genoa, while the second one is in Milan and is mainly used by La Spezia. Several plans can be found in the port

websites discussing the possibility of using other inland ports in order to serve other markets or to enlarge the railway activity.

Considering the network data about infrastructural constraints and distances, official statistics have been used in order to collect all the required information from the official databases published by the Ligurian Region (i.e. Regional Logistics Plan) and the infrastructure managers (i.e. *Rete Ferroviaria Italiana* for railways and *Autostrade per l'Italia* for the motorways). Then, considering the collected data, the road and rail networks have been derived: as underlined by the Regional Logistics Plan (Regione Liguria, 2010), the main hinterland connections are represented by three main inter-regional links (Genoa-Milan/Turin; Savona-Turin; La Spezia-Parma; La Spezia-Leghorn) and one intra-regional one (Ventimiglia-La Spezia) that allows to easily reach the main destinations using both motorways and railways. Motorway and railway networks use similar origin-destination routes; moreover the rail infrastructures are characterised by several technical constraints that are currently increasing the costs of freight transport. In particular, the rail infrastructural constraints are related to the slope of the rail tunnels, the presence of only one track in some of the mixed freight/pax rail trunks, and the gabarit of tunnels. These limitations affect the costs of the rail operations in three ways: reducing the length of the trains and consequentially their capacity; increasing the number of locomotives needed to overcome steepest rail trunk; diminishing the number of possible daily trains together with their time schedule. Note, for instance, that concerning the Ligurian rail network, the maximum number of daily trains varies from a minimum of 60 to a maximum of 180 trains per track (including the passenger ones).

On the other hand, the motorways do not present similar constraints, even if bottlenecknesses are quite frequent on the highways, having a variable number of lanes (impacting on the overall capacity) depending on the specific highway. Moreover, in all three ports some of the freight truck movements involve the city centre area, thus impacting on the urban congestion level.

As far as costs is concerned several studies have been taken into account in order to properly derive the main cost components and to evaluate possible distribution patterns. Table 1 resumes the main sources used for the present study. Note that the distribution patterns differ for: i) the network distribution with or without inland ports; ii) the import flows for the three transport modes (road, rail and intermodal).

Table 1: Sources used in the paper

<i>Data</i>	<i>Collected Data</i>	<i>Source</i>	<i>Data used in the model</i>
Traffic Flows	<i>Official Data</i>	<i>Italian National Custom Agency</i>	<i>Node-to-node flows (TEU)</i>
Road Network Characteristics	<i>Official Data</i>	<i>Autostrade per l'Italia</i>	<i>Node-to-node distance (km)</i>
Rail Network Characteristics	<i>Official Data</i>	<i>Rete Ferroviaria Italiana</i>	<i>Node-to-node distance (km)</i>
Road Transport Costs	<i>Official Data</i>	<i>Italian Ministry of Transport</i>	<i>1.6€ TEU/km</i>
Rail Transport Costs	<i>Estimation from the literature review, validated through rail operator interview</i>	<i>Baumgartner, 2001; Grosso, 2011</i>	<i>1.96€ TEU/km [avg.]</i>
Inland Costs	<i>Estimation from the an interview, validated through literature review</i>	<i>Regional Logistics Plan (2010)</i>	<i>Handling and Activation Costs</i>
External Transport Costs	<i>Estimation from the official EU report and related updates</i>	<i>Handbook on estimation of external costs in the transport sector (yy 2008-2014)</i>	<i>Noise, Congestion and Pollution</i>

Official documentation has been used for deriving the private cost component; in particular, the road transport cost has been established from the official minimum tariffs set by the Italian Ministry of Transport; for the year 2011, tariffs vary with respect to the distances and the kind of truck from a minimum of 1.3 €/km to a maximum of 1.9 €/km (Italian Ministry of Transport, 2015); consequently, an average value of about 1.6 € for TEU/km has been used in this study. Since there are not official data related to the rail transport costs, different values have been compared through a literature review (e.g. Baumgartner, 2001; Grosso, 2011) and validated by an interview with a rail company. The estimation chosen is an average value of about 1.96 € TEU/km, with high variations depending on constraints and distances (costs are actually estimated using an average cost value per train). For what concerns the infrastructures, in the present study only the cost associated with the inland ports is considered; in particular, the activation and handling costs have been included. The handling costs represent the operative costs, which in turn are used for simulating the transshipment cost. Activation costs represent the cost to invest in an inland port and to open it: they are included in the model as a charge paid by the users of that facility (calculated as the total cost of activation divided per years and number of users). Both handling costs and activation costs have been derived from a direct interview to a manager of an inland port operating in the North of Italy and using the data included in the Regional Logistics Plan (Regione Liguria, 2010).

2.2 The external costs

The external costs included in the analysis are noise, pollution and congestion. As suggested by the *Handbooks on Estimation of External Costs in the Transport Sector* (e.g. Maibach et al., 2008), the estimation of such kind of costs is not easy and depends on the particular characteristics of the surrounding environment (e.g. urban or rural areas), the vehicle (e.g. EURO policy for road vehicles) and of the infrastructure (e.g. motorways or urban roads). Moreover, some of the related costs might depend on the average travelling speed and other travel elements. The above mentioned characteristics affect the correct value to be considered in any external costs evaluation. According to the characteristics of the analysis – that focuses on distribution paths within a macro-region – and considering that the majority of the interurban distribution trips is usually made by similar vehicles (Consulta Nazionale per l’Autotrasporto e la Logistica, 2011), and using motorways, average values for the external costs have been used. Therefore, as in Maibach (2008), an average value of 32 €/km is used for computing the congestion costs to be paid for the road flows leaving the ports. The average value used for the road pollution is 5 €/km, while the rail pollution is estimated about 42 €/km per train (2.3 €/km/FEU²). Finally, the average value used for the road noise is 1.5 €/km, while for the rail is 3.4 €/km/FEU. Since ports are the only urban areas that are taken into consideration, for the last mile path connecting the port urban values has been considered (that approximately double the average values per kilometer but have just a marginal effect on the total considered costs).

3. The proposed model

Different distribution solutions, in which some inland ports can be activated and used in an existing intermodal network, are evaluated thanks to a MILP model here below described. Note that the present model represents an extension of that proposed in Ambrosino and Sciomachen (2014) for solving an intermodal hub location problem. In particular, the present model allows to define the optimal flow distribution that minimizes the overall costs, as described in the previous section, while defining the optimal location of inland ports in the intermodal distribution network. A classification of location allocation problems is furnished in Azarmand and Neishabouri (2009).

The main aim of this analysis is to understand the effect of different distribution systems on both modal split and costs; further, we analyse the impact of variations in the external costs on both the flow modal split and the location decisions.

² The estimations have been based using the “intermodal transport unit” (in Italian “Unità di Trasporto Intermodale” (UTI)) as unit of measure. A UTI is approximately what a standard rail car can carry on (so approximately 1 FEU).

The intermodal distribution network under investigation is represented by a weighted digraph $G=(V,E)$. V is the set of nodes; it is split into 4 subsets, namely:

- 1) the seaports (V_O), representing the origin nodes of the flows in G ;
- 2) the destination nodes (V_D), i.e. the demand nodes of G ;
- 3) the candidate nodes (V_H), representing the possible sites where to locate/activate an inland port in G ;
- 4) the transition nodes (V_T), necessary for being able to represent all the possible paths of the flow in the network and, consequently, computing the externality costs as a function of the flow in G .

E is the set of oriented arcs representing connections between nodes of V ; in particular, $E = \bigcup_{m \in M} E_m$,

where set E_m represents the arcs traveled in G using the m -th transportation modality, $m \in M$.

M is the set of transport modalities. In this paper, $|M| = 2$ and set E is split into 2 subsets:

- 1) E_T , representing the road connections;
- 2) E_W , representing the railway connections.

Before presenting the mathematical formulation of the problem under consideration, let us introduce the required additional notation.

Constants

Nodes' weight

Cf_h fixed cost for locating an inland port at node h , $\forall h \in V_H$

Cv_h unit handling cost at inland port h , $\forall h \in V_H$

K_h maximum handling capacity of inland port h , $\forall h \in V_H$

Q^m_h in/out capacity of inland port h related to transport modality m , $\forall h \in V_H$, $\forall m \in M$

Ce_i unit road congestion cost for the outflow from node i , $\forall i \in V_O$

d_{ij} flow demand from node i to node j , $\forall i \in V_O$, $\forall j \in V_D$

Arcs' weight

c^m_{ij} transportation cost of arc (i,j) for transport modality m , $\forall (i,j) \in E_m$, $\forall m \in M$

cp^m_{ij} pollution cost of arc (i,j) for transport modality m , $\forall (i,j) \in E_m$, $\forall m \in M$

cn^m_{ij} noise cost of arc (i,j) for transport modality m , $\forall (i,j) \in E_m$, $\forall m \in M$

q^m_{ij} flow capacity of arc (i,j) for transport modality m , $\forall (i,j) \in E_m$, $\forall m \in M$

Thus, having in mind the distribution network described above, in the definition of the best distribution solution it is possible to decide:

- the number of inland ports to locate/activate and their location, by choosing among the candidate nodes (V_H) (network design problem)
- the transportation modes and the paths to use for shipping the required volume of goods from the origin nodes (V_O) to the destination ones (V_D) (flow optimization problem).

The following variables are then defined:

flow variables:

$x_{ij}^m \geq 0$ flow on arc (i,j) with transport modality m , $\forall (i,j) \in E_m, \forall m \in M$

$x_h \geq 0$ flow managed by node h , $\forall h \in V_H$

$x_i^T \geq 0$ road outflow from node i , $\forall i \in V_O$

inland port location variables:

$y_h \in \{0,1\}$, $\forall h \in V_H$, indicate which inland ports are chosen; in particular, $y_h = 1$ if node h is chosen, $y_h = 0$ otherwise.

The objective function of the proposed model is devoted to the minimization of the following cost components:

- ✓ inland opening and operative costs

$$\sum_{h \in V_H} C f_h y_h + \sum_{h \in V_H} C v_h x_h$$

- ✓ transportation costs

$$\sum_{m \in M} \sum_{(i,j) \in E_m} c_{ij}^m x_{ij}^m$$

- ✓ externalities costs

$$\sum_{m \in M} \sum_{(i,j) \in E_m} c p_{ij}^m x_{ij}^m + \sum_{m \in M} \sum_{(i,j) \in E_m} c n_{ij}^m x_{ij}^m + \sum_{i \in V_O} C e_i x_i^T$$

Note that, activation and handling costs are associated with each candidate node (V_H); these costs depend on both the size and handling capacity of the candidate inland port. External costs are included in the analysis in order to make externalities part of the decision making process of the transport users; pollution and noise costs are proportional to the flow on the arcs of the network, while congestion costs are proportional to the road flow leaving ports.

The sets of constraints of the proposed model are the following. They are used for:

- ✓ Defining variables related to the in /out flows:

$$\sum_{m \in M} \sum_{i \in V \setminus V_h} x_{ih}^m + \sum_{m \in M} \sum_{i \in V \setminus V_h} x_{hi}^m = x_h, \forall h \in V_H$$

x_h is computed as the sum of the flows entering and leaving the inland port h with any transport modality m

$$\sum_{j \in V \setminus V_o} x_{ij}^T = x_i^{T-}, \forall i \in V_o$$

x_i^{T-} is computed as the sum of the road flows leaving node i .

- ✓ Satisfying o-d demands

$$\sum_{m \in M} \sum_{j \in V \setminus V_o} x_{ij}^m = \sum_{j \in V_D} d_{ij}, \forall i \in V_o$$

The total flow leaving origin node i must be equal to the sum of the $o-d$ demands having node i as origin node.

$$\sum_{m \in M} \sum_{i \in V \setminus V_D} x_{ij}^m = \sum_{i \in V_o} d_{ij}, \forall j \in V_D$$

The total flow entering destination node j must be equal to the sum of the $o-d$ demands having node j as destination node.

- ✓ Satisfying capacity constraints on arcs

$$x_{ij}^m \leq q_{ij}^m, \forall (i, j) \in E_m, \forall m \in M$$

The flow passing through arc (i, j) by transport modality m can not be greater than the flow capacity of the arc.

- ✓ Satisfying capacity constraints on nodes:

in/out flow capacity of inland ports for road and rail modality

$$\sum_{i \in V \setminus V_h} x_{ih}^m + \sum_{i \in V \setminus V_h} x_{hi}^m \leq Q_h^m, \forall h \in V_H, \forall m \in M$$

The total in and out flow by transport modality m must be lower than the given capacity of the inland port.

$$\sum_{m \in M} \sum_{i \in V \setminus V_h} x_{ih}^m + \sum_{m \in M} \sum_{i \in V \setminus V_h} x_{hi}^m \leq K_h y_h, \forall h \in V_H$$

The total flow entering and leaving inland port h can not be greater than its handling capacity (no flow can enter/leave the node if the inland port is closed, i.e. $y_h = 0$).

- ✓ Flow conservation constraints:

At transition nodes

$$\sum_{j \in V} x_{ij}^m = \sum_{j \in V} x_{ji}^m, \forall i \in V_T, \forall m \in M$$

The flow entering a transition node i by modality m must also leave it by the same modality.

At inland ports

$$\sum_{m \in M} \sum_{i \in V \setminus V_h} x_{ih}^m = \sum_{m \in M} \sum_{i \in V \setminus V_h} x_{hi}^m, \forall h \in V_H$$

The total flow entering an inland port must also leave it (but the modality may change)

In the next section the results obtained by solving the proposed model by the spreadsheet Excel are discussed.

4. The case study results

In the network under investigation there are 73 rail arcs and 85 road arcs; the number of nodes is 53, split into 3 ports, 3 candidate inland ports, 13 destinations³ and 34 transition nodes. The total import flow transferred to the 13 destination nodes is 431,811 TEUs; such flow corresponds to the volume of containers moved by the three ports in 2011 and transferred to the hinterland.

Firstly, the MILP model proposed in the previous section has been used for defining the routes and the modalities for shipping goods from the origin seaports to the destination nodes in order to minimize the total costs in different scenarios. In particular, the first scenario doesn't consider the inland ports; a second scenario has three operative inland ports, and the last scenario considers the number of inland ports to activate as a decision variable. Referring to the first two scenarios, the model is used only to define the optimal flows in the existing network, while in the last case the model is used for defining the best distribution network (i.e. a network design problem is solved) (see subsection 4.1).

³ Destinations are represented by the main Nuts-3 destinations for each port that do not share the majority of the network. If the majority of the network is shared by a certain destination (e.g. North East provinces) the nodes are aggregated.

Secondly, the model has been used for performing a sensitive analysis with the aim of understanding the variation in the modal split and costs composition (i.e. transportation costs, external costs and inland costs) when varying the rail capacity of both the port outflows and the inland ports (see sub-section 4.2).

Finally, the model has been used for evaluating its robustness when varying the external costs. In particular, the effects on the location of inland ports, the modal split and the costs composition are analysed (see sub-section 4.3).

4.1 Analysis of the optimal solution and other scenarios

Since one of the main scope of the paper is to investigate the impact of the internalization of congestion, noise and pollution costs in the decision process, in Table 2 different solutions obtained by solving the model presented in Section 3 are compared in terms of rail/road modal split. Different external costs are included in the analysis: six cases are considered which differ each other for the type of external costs included in the decision process. More precisely, cases 1 – 6 reported in Table 2 include inland ports costs (IC), transportation costs (TC) and external costs (EC) with their components congestion (C_e), pollution and noise for road transport and pollution and noise for rail transport (c_p , c_n).

Table 2 reports the optimal solutions of the three scenarios described above (e.g. no inland ports, three inland ports, optimal number (Y^*) of inland ports). For each scenario, in Table 2 are shown the cost composition (% IC - % TC - % EC) and the modal split of the flows in the network. In particular, the modal split is detailed for the outflow from seaports (OUT-F-O), inflow at inland ports (IN-F-I), outflow from inland ports (OUT-F-I) and inflow at destination nodes (IN-F-D).

Table 2: Optimal solution of three scenarios solved by considering six different degrees of internalization of EC

		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Inland port costs (IC)		x	x	x	x	x	x
Transportation costs (TC)		x	x	x	x	x	x
External costs (EC)	Ce		x		x		x
	cp + cn - road			x	x	x	x
	cp + cn - rail					x	x
Scenario 1 (no inland ports)							
Cost Composition	% IC % TC % EC	0.00 100.00 0.00	0.00 80.51 19.49	0.00 24.61 75.39	0.00 23.26 76.74	0.00 20.52 79.48	0.00 19.56 80.44
Modal Split	Road Rail	Road Rail	Road Rail	Road Rail	Road Rail	Road Rail	Road Rail
	OUT- F- O	91.54 8.46	79.72 20.28	79.72 20.28	79.72 20.28	79.72 20.28	79.72 20.28
	IN - F- I	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00
	OUT - F - I	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00
	IN - F - D	91.54 8.46	79.72 20.28	79.72 20.28	79.72 20.28	79.72 20.28	79.72 20.28
Scenario 2 (3 inland ports)							
Cost Composition	% IC % TC % EC	9.76 90.24 0.00	7.96 73.99 18.05	2.67 25.35 71.98	2.51 23.91 73.58	2.15 20.43 77.42	2.05 19.48 78.47
Modal Split	Road Rail	Road Rail	Road Rail	Road Rail	Road Rail	Road Rail	Road Rail
	OUT- F- O	91.54 8.46	79.72 20.28	79.72 20.28	79.72 20.28	79.72 20.28	79.72 20.28
	IN - F- I	0.09 3.31	0.09 3.31	13.41 0.00	13.41 0.00	12.87 0.00	12.87 0.00
	OUT - F - I	0.00 3.40	0.00 3.40	0.00 13.41	0.00 13.41	0.00 12.87	0.00 12.87
	IN - F - D	91.45 8.55	79.63 20.37	66.31 33.69	66.31 33.69	66.85 33.15	66.85 33.15
Scenario 3 (Optimal network)		No inland ports	No inland ports	2 inland p. (AL-MI)	2 inland p. (AL-MI)	1 inland p. (MI)	1 inland p. (MI)
Cost Composition	% IC % TC % EC	0.00 100 0.00	0.00 80.51 19.49	1.88 25.56 72.56	1.77 24.09 74.13	0.65 20.56 78.79	0.62 19.60 79.78
Modal Split	Road Rail	Road Rail	Road Rail	Road Rail	Road Rail	Road Rail	Road Rail
	OUT- F- O	91.54 8.46	79.72 20.28	79.72 20.28	79.72 20.28	79.72 20.28	79.72 20.28
	IN - F- I	0.00 0.00	0.00 0.00	13.41 0.00	13.41 0.00	6.71 0.00	6.71 0.00
	OUT - F - I	0.00 0.00	0.00 0.00	0.00 13.41	0.00 13.41	0.00 6.71	0.00 6.71
	IN - F - D	91.54 8.46	79.72 20.28	66.31 33.69	66.31 33.69	73.02 26.98	73.02 26.98

Looking at Table 2 readers can note that when there is no inland port in the network, the rail flow is conditioned by the rail capacity of seaports. The presence of external costs (even the presence of only one type of these costs, i.e. congestion costs) modifies the modal split of the outflow from seaports (OUT-F-O) in favour of rail transport up to the maximum capacity (i.e. 20.28%). Note that from case 2 to case 6, the flows on the network are unchanged.

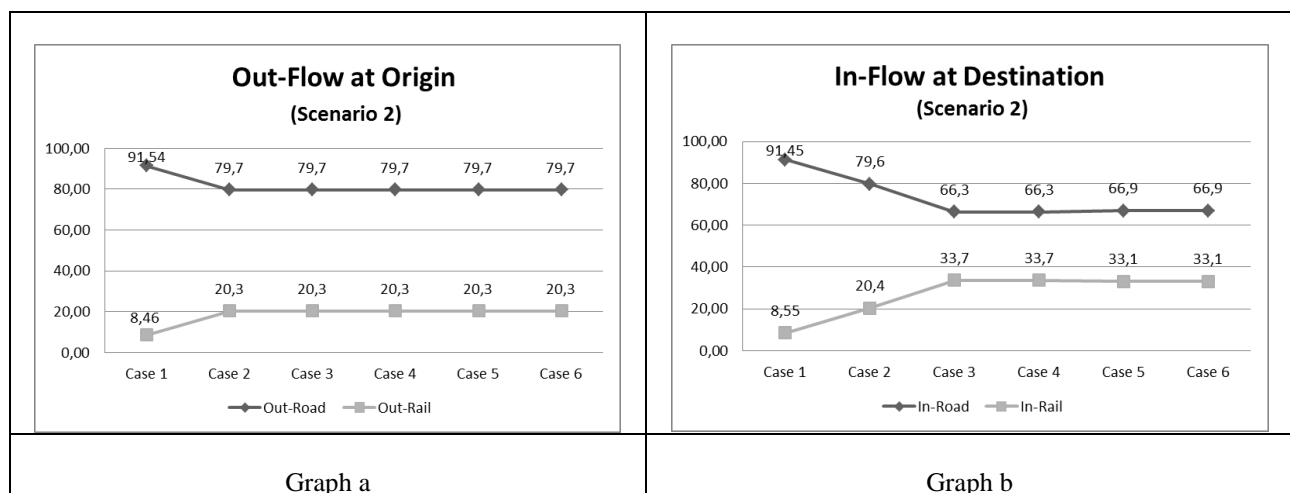
When the network is designed with three inland ports, the outflow from seaports is still affected by the rail capacity, but the presence of intermodal inland ports permits to obtain a modal split with

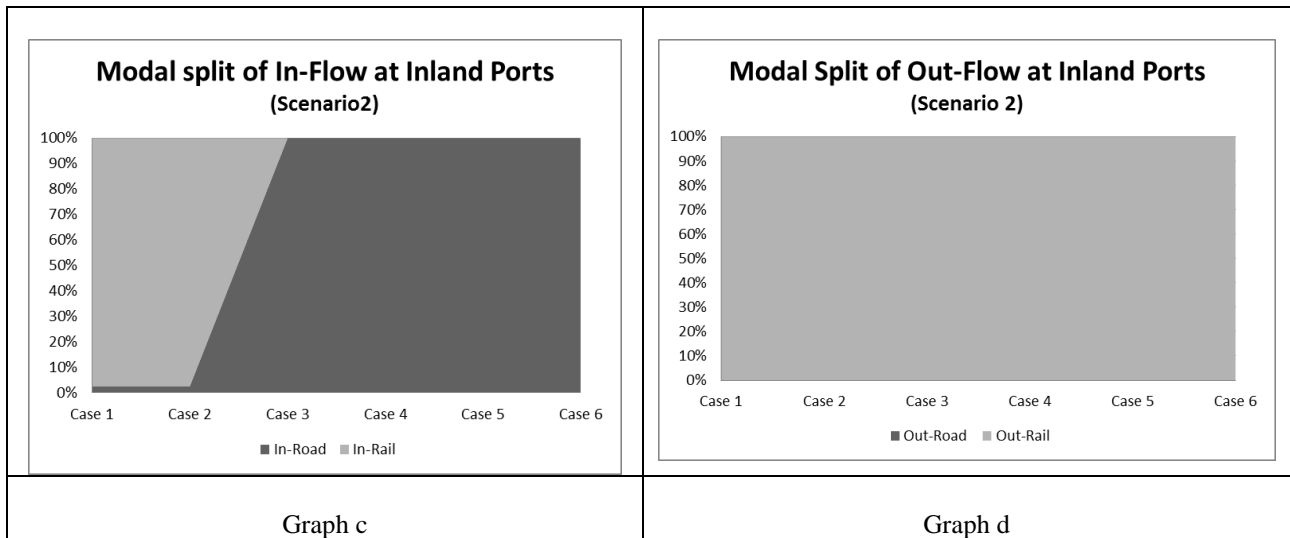
higher percentage of rail in the inflows at destination nodes (IN-F-D). When the external costs are paid only on the road modality, this percentage becomes 33.69% (cases 3 and 4), with a percentage of intermodal flow equal to 13.41%, that is the flow entering the inland ports by road and leaving them by rail (IN-F-I and OUT-F-I). In cases 5 and 6, where the external costs are paid both on the rail and road transport, the modal split is different; in particular, the change of modality at inland ports regards the 12.87% of the total flow of the network, while the rail flow at the destination nodes is 33.15%. Note that these values are lower than the percentages obtained in the previous cases.

It is important to notice how some of the values related to Scenarios 2 and 3 might seem against the common practice (e.g. truck flows out from the port generating rail traffic once arrived at the inland port); however, the effect of the cost internalization and the related rail capacity constraints contribute to generate this situation as optimal solution of the model (once again note the importance of internalizing the external costs in order to promote the modal split).

In graphs a), b) c) and d) reported in Figure 2 it is possible to note the behaviour of the modal split of the flows at the origin nodes, destination nodes and inland ports when varying the types of external costs included in the decision process (from cases 1 to 6). The considered scenario has three operative inland ports. The congestion cost on the road flow leaving the origin nodes has an increasing effect on the rail flow from ports, while doesn't modify the modal split at inland ports. When the pollution and noise costs are included in the analysis together with the congestion cost rail modality is used as much as possible; this goal is reached by both saturating the rail capacity of the flows leaving the ports and using inland ports as modal change nodes (the road flow enters the inland port and the rail flow leaves it).

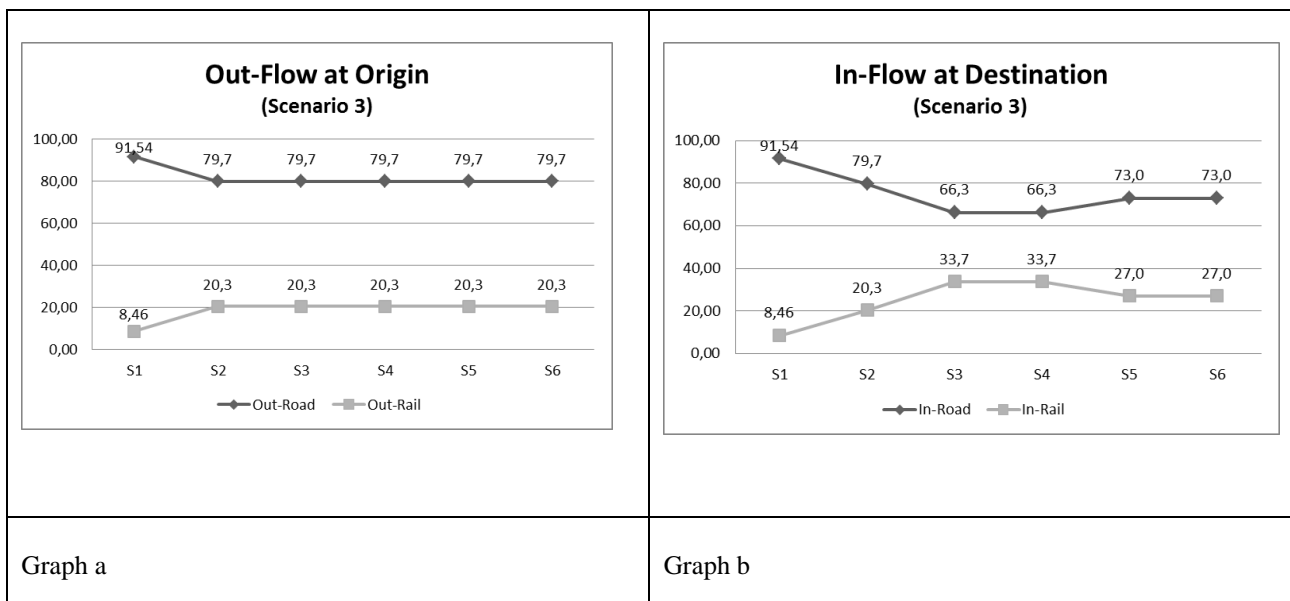
Figure 2: modal split behaviour related to Scenario 2





The last rows of Table 2 refer to the optimal network obtained by solving the model in such a way to define the number of inland ports to activate (Y^*). When the external costs are either not included or only related to the congestion costs (cases 1 and 2) the optimal network is designed without inland ports (e.g. $Y^*=0$). The situation is different when external costs refer only to the road transport. In fact, in cases 3 and 4 the optimal network presents two inland ports ($Y^* = 2$) that are able to increase the rail flows, thus reducing the external costs of the system. Finally, in cases 5 and 6 the optimal solutions present only one inland port ($Y^* = 1$). Graphs a) and b) in Figure 3 show the different modal split in the six cases at the origin and destination nodes.

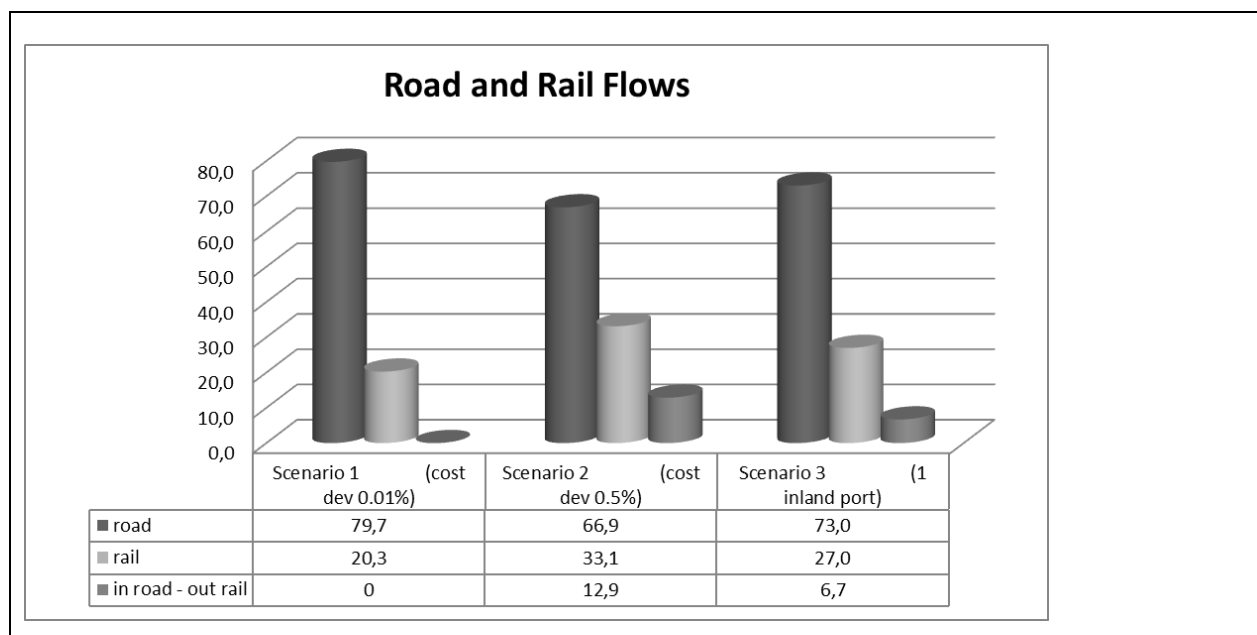
Figure 3: modal split behaviour at origin and at destination nodes related to Scenario 3



The behaviour of the modal split of the outflows at the origin nodes obtained by solving the network design model (Scenario 3) is equal to that observed in graph a) of Figure 2. For what concerns the inflow at the destination nodes, by looking at graph a) of Figure 2 it is clear the effect of a greater internalization of the external costs on the modal split.

In the graph of Figure 4 a comparison of the inflow modal split at the destination nodes in the three considered scenarios is reported. The analysis is done when all types of external costs are included in the decision process (case 6). The graph shows the road and rail flow reaching the destination nodes of the network and the intermodal flow passing through the activated inland ports. For scenarios 1 and 2, the percentage cost deviation with respect to the total cost of the optimal solution with only one inland port is also reported. Note that the solution with three inland ports allows to increase the modal split in favour of the rail transport, but it is worse than the solution with one inland port; the difference is only 0.5%, but in absolute term represents about 3.5 million Euros.

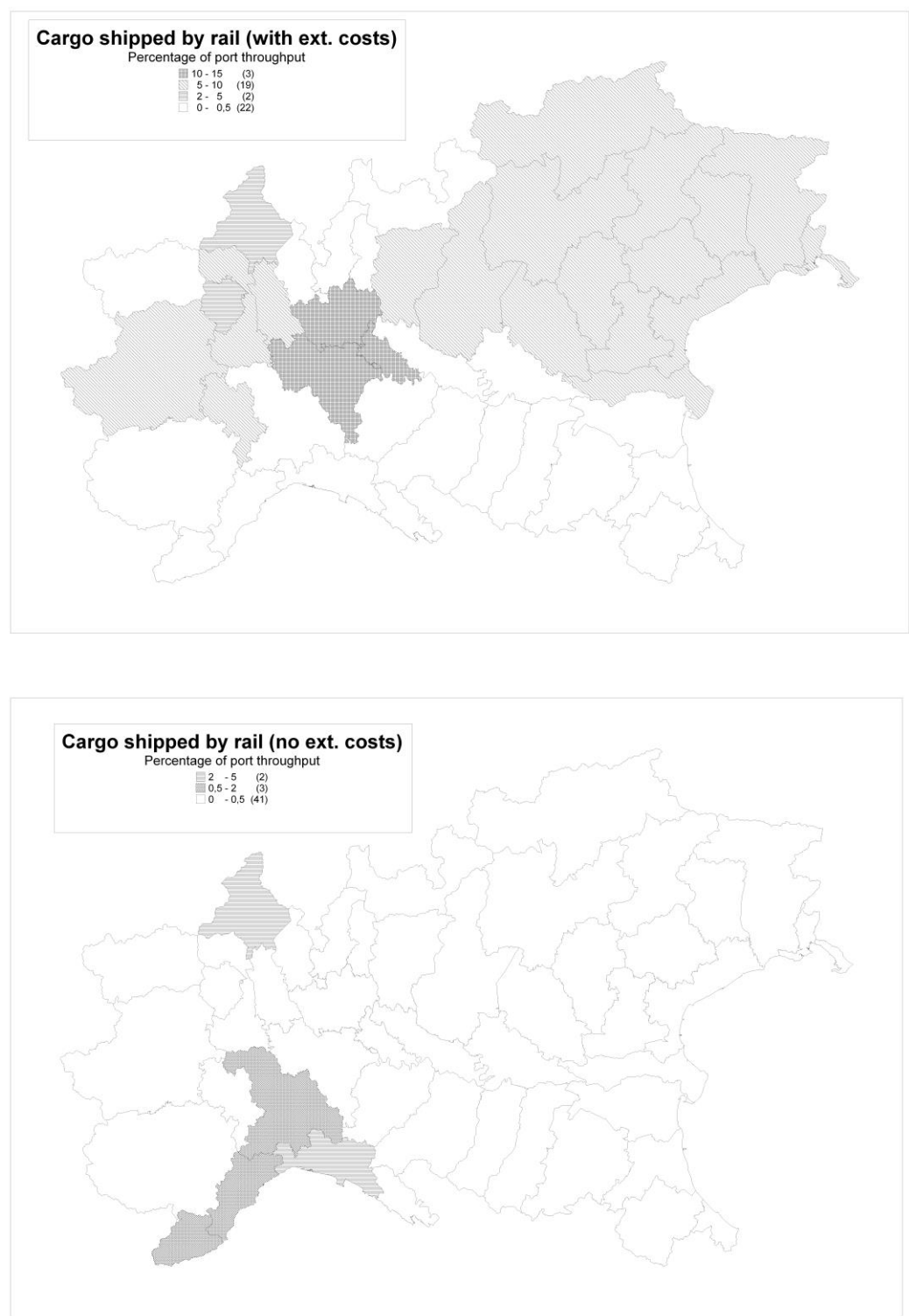
Figure 4: modal split comparison among the 3 scenarios



Case 6 is here analysed in more detail. In the optimal solution of the network design and flow problem one inland node is chosen; it is located in Milan. Readers can easily note that all the flow entering the inland port by road leaves it by rail; this implies that 6.7% of the flow uses the intermodal transport modality. The modal split at the destination nodes is 73.02% by road and 26.98% by train. The

corresponding optimal flows are depicted in Figure 5, where the first map shows the improvement guarantee by the internalization of the external costs, while the second map shows the “actual” rail quota of port cargo shipped by train per province.

Figure 5 – comparison between solutions with and without external costs



The costs related to the optimal solution are reported in Table 3.

Table 3: Optimal solution

Activation costs		0,617 %	
Handling costs		0,001 %	
<i>Total inland costs</i>			<i>0,618 %</i>
Transportation costs	Road	14,018 %	
	Rail	5,582 %	
<i>Total transportation costs</i>			<i>19,600 %</i>
External costs	Road	58,661 %	
	Rail	16,455 %	
	Congestion at the ports	4,665 %	
<i>Total external costs</i>			<i>79,782 %</i>
<i>Total costs in the system</i>			<i>100.000%</i>

The main aim of this analysis is to understand if it is possible to obtain a better modal split in favour of the train modality.

Considering the results given above, it is worth noting that without the external costs the model depicts a situation quite similar to the real case; the inland ports can facilitate the intermodal transport even if they are not effective in balancing the distribution of goods between the rail and road modes. Moreover, since the model doesn't consider the impact of the value added services made within the logistic parks, inland ports act merely as transit points and so they only contribute to the rationalization of the transport flows.

Moreover, the rail outbound flows from the ports reach the maximum capacity level at all three ports, creating a bottleneck in the rail branch connecting Genoa to the Po Valley (which is a rail track used also by the trains originated in La Spezia and Savona), thus limiting possible further use of the rail network. This situation also explains why most of the inbound flows to the inland ports come from the road transport, while the outbound flows mainly use the rail transport. In fact, the external costs heavily impact on the roads such that the rail connections are chosen whenever possible; this is true for cases 3 and 4. Further, the introduction of inland ports allows to partially overpass the present infrastructural limitations and increase the rail quota even generating new trains. This finding can be considered strategic for future transport policies; in fact, many North Italian inland ports are currently operating just as urban distribution centres. In this scenario, only few trains are organized to serve some Italian Provinces and normally cargoes just enter by train but are successively distributed by road.

Eventually, it is interesting to underline how the location of different inland ports impact in several ways on the model solutions. Just to give an idea, Turin, which is located on the West side of the port hinterland, has no impact on the distribution of the cargo flows when the external costs are neglected and a reduced effect when they are considered. On the other hand, Alessandria and, mainly, Milan have a pivotal role in the network and their impact is strategic when the external costs are considered. Despite the rail infrastructure limitations behind the port, the inland ports seem to have a strategic role in promoting intermodal transport enhancing the potential benefit of the internalization of the external costs. Considering the total cost of the system, the best solution is represented by the scenarios in which only Milan is selected as inland port (even if when Milan and Alessandria are both activated as inland ports, they allow to reach the highest percentage of rail at destination nodes i.e. 33.69%).

4.2 Sensitive Analysis on the rail capacity

From the results described in the previous section, the crucial points of the network seem to be the in/out flow rail capacity of the inland ports and the outflow rail capacity of the ports. Thus, an analysis by varying the rail capacity has been performed starting from the optimal solution of the model given in section 3. This analysis focuses on case 6 (i.e. that is with external costs for congestion, pollution and noise). The rail capacity has been incremented of different values in such a way to verify the impact on both the modal split and the total costs and their partition among transportation, externalities and inland port costs.

It is interesting to note that, by doubling the rail capacity at the sea ports the rail flow at the destination increases from 26.98% to 36.37%, while when triplicating it the rail flow reaches its highest value of 49.78%. Finally, by increasing (triplicating) the rail capacity at the inland ports it is possible to increment these percentages up to more than 60%. In this last case, the variation in the total cost of the network is about 5.29%, while when doubling the rail capacity at the sea ports this variation is about 1.77%; note that external costs represent the cost component having the biggest reduction among the different cost items.

4.3 Sensitive Analysis on the external costs

The last analysis here reported concerns a further investigation on the external costs related to case 6. The main aim of this analysis is to understand for which levels of external costs the optimal solution of the model presented in Section 3 changes. Each component of the external costs (i.e. congestion at the origin nodes, pollution and noise on the arcs of the network) are increased - or decreased - of a

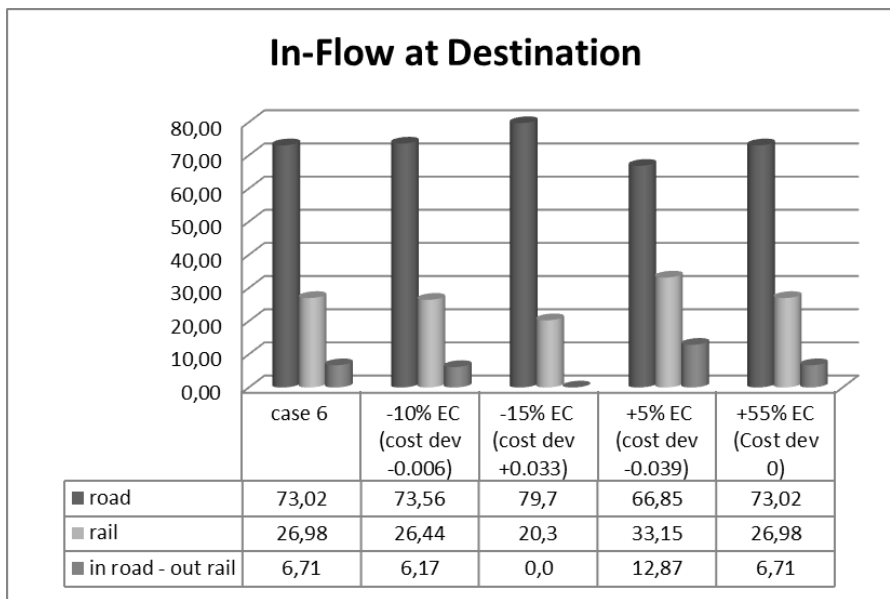
given percentage. Remind that the optimal solution of case 6 is characterized by one inland port located in Milan and 73.02 % road and 26.98 % rail modal split at the destinations, with an intermodal flow of 6.71%.

A 10% decrease of the external costs makes the previous result no more optimal; the new optimal solution is based on the opening of an inland port in Alessandria (while Milan is not activated); the modal split remains nearly the same. Moreover, by reducing the external costs of 15% the best solution changes again: the rail share decreases and none inland port is necessary.

When considering a growth in the external costs, the solution of case 6 remains optimal up to the external costs reaches the 5% of them. At this level a new optimal solution, characterized by two operative inland ports, is found. The railways are used for more than 33% and the intermodal flows exceed the 12%. Another variation in the solution is obtained when the external costs increase of 55%. In this case, the solution found is equal to the optimal solution of case 6: one inland port located in Milan. It is interesting to underline that this switch in the optimal solution is mainly due to the fact that an increase of the external costs does not have any effect if the infrastructure and the facility capacity is not upgraded consequently. In fact, the +55% scenario has a negative effect in comparison with a lighter increase of the paid external costs (e.g. +5%) since, without an upgrade of the rail facilities and infrastructure, all flows choose the shortest path, thus reducing the attractiveness of the intermodal transport, passing through the inland ports and, consequentially, increasing the overall path length.

The above described results are reported in Figure 6, where some information about the cost deviation of the different solutions from the cost of the optimal solution of case 6 are also provided. It is important to note that, for obtaining comparable data, this deviation is computed on the transportation and inland ports costs, without including the external costs.

Figure 6: modal split behaviour in case of different external costs



5. Conclusion

The great share of freight traffic choosing roads to reach its final destination even for medium and long distances proves that choices made upon the private generalised cost of transport determine inefficiencies and waste of resources. The inclusion of the cost of externalities in the behavioural choices of the economic agents contributes to reach a more balanced modal shift. This is further supported by the location on inland ports where freight flows may be rationalised and optimised, allowing using the means of transport that better fit any specific freight flow in respect of its volume and distance to be travelled.

In the present paper the freight outflows of the seaports located in the North-West coast of Italy are modelled on the rail and road networks in order to understand how the use of some inland ports could affect the modal shift in freight transport.

The results shown in Section 4 underline how the internalization of external costs might foster a more balanced modal split between rail and road transport: in normal conditions the containerised goods moved by road cover more than 90% of the transport share but the internalization of external costs would drastically change this situation more than doubling the cargo shipped by train. Despite these positive effects, the proposed model highlighted how infrastructural limitations in some rail trunk might limit the positive effects of the internalization of external cost due to the rapid achievement of the current maximum capacity. The use of a system of inland ports located in the North Italian regions

might – at least partially – copes this infrastructural gap, increasing the rail share up to 33%. Thus the increasing efficiency of the flow distribution given by inland ports seems to be strategic in order to foster a more balanced modal split. Interestingly, one of the optimal solutions found by our model is similar to the results achieved by Limbourg and Jourquin (2009) that highlighted how Milan might be an optimal rail-road terminal in their network.

Furthermore, future researches will be dedicated to the discussion of specific transport policies able to incentivize transport solution through cost internalization tools and to aggregate flows on specific inland ports, with the aim to reduce possible externality concentrations in some specific points of the network, such as the port city centres. Moreover, Ligurian ports represent a great share of the containerised traffic generated by the North Italian region, nevertheless future extensions might consider also other Italian port systems (e.g. North Adriatic ones) that serve a similar hinterland.

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